

THE GEOPHONE (Prakla)

Its essential features and the related test procedures A Report in two parts given by G. Braun

The geophone has already been a subject of an earlier article in the former "PRAKLA -SEISMOS-Rundschau", No. 41, 1970. The geophone types in use at that time had reported in a humorous way on their life with a seismic crew, but only some brief technical notes were given. This time we present a comprehensive technical account on this instrument which is so fundamental to seismics. Because of the length of this article we have divided it into two parts (the second of which will appear in the Report 4/ 76). By doing so, we are complying with the wishes expressed several times by many of our readers.

Significance of the Geophone

PRAKLA-SEISMOS' seismic reflection parties are equipped with about 3000 geophones each. This large number could be the reason for an undervaluation of this small but very important seismic instrument. Harsh field operations undoubtedly may explain such an attitude; but some essentials should always be taken into consideration:

- The geophone is the first member in a chain of data collecting devices. Information lost at this point cannot be regained by any subsequent processing procedure. As far as information is adulterated here, additional expenditure is necessary.
- The failure of a geophone is in fact one of several possible instrument faults in collecting seismic data. However, as long as there is no quantitative information relative to its own error influence on the final result, every single instrument failure of the whole seismic chain must be kept as small as possible. Above all, the possible presence of more important failures in the time-measuring chain - on which the seismic method is based – should not lead to disregarding or forgetting smaller failures, as they may be caused by damaged geophones.

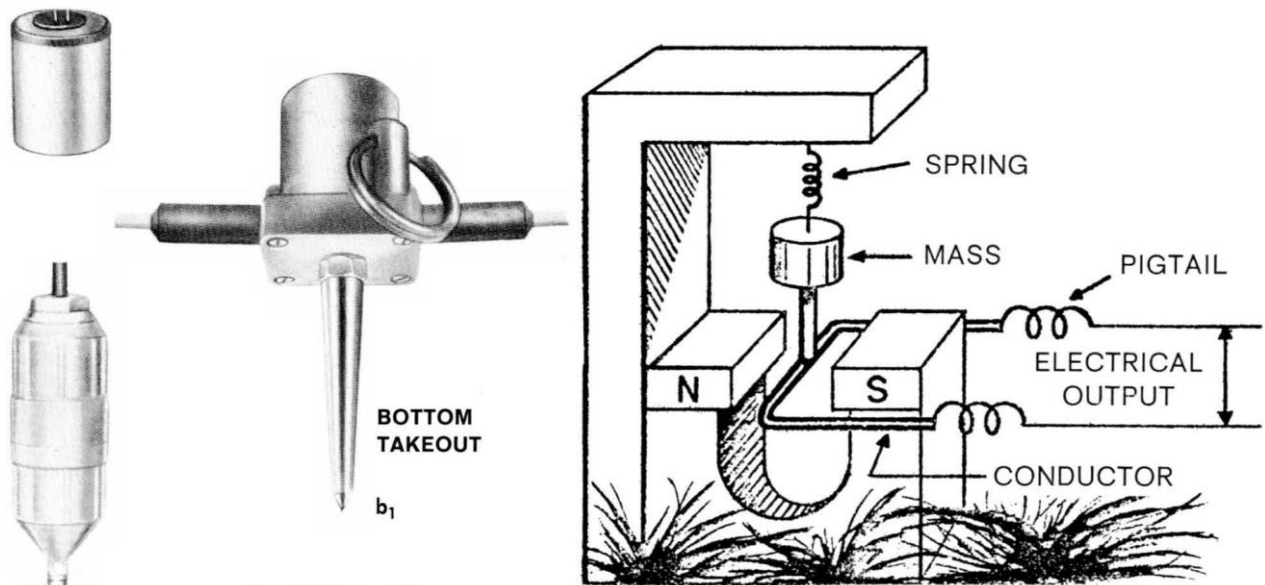
Function of the Geophone

An electrical conductor being moved through a magnetic field develops a voltage across its ends. This effect is utilized by the electrodynamic geophone, see sketch figure 1.

The mass of the geophone can be regarded as being in a resting position when measuring seismic events. Every motion of the ground and of the geophone case coupled firmly with it results in a relative motion between conductor and case.

As the magnet is rigidly attached to the case, this motion produces a relative motion between conductor and magnetic field.

Fig.1 Diagrammatic sketch of a geophone



a) Geophone system b_1) b_2) b_3) Types of geophone cases (Sensor and Geospace)

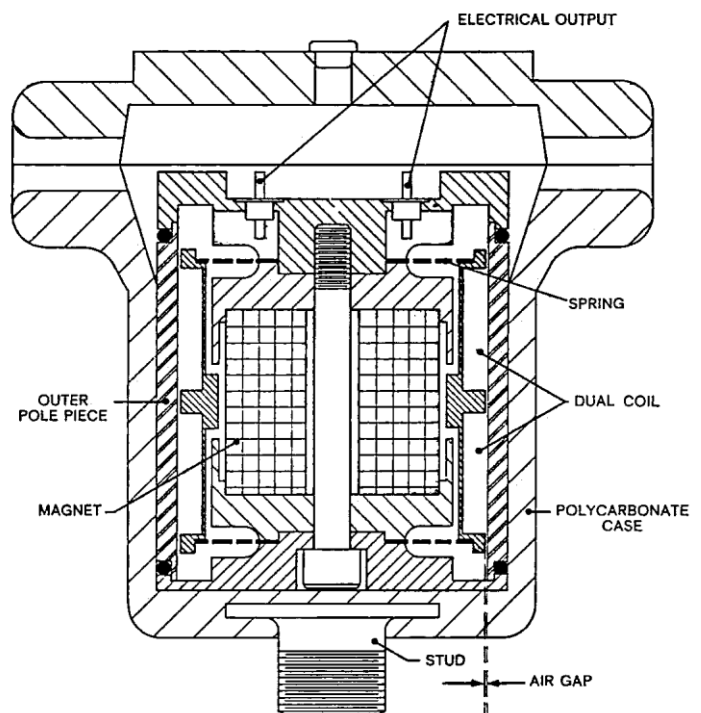


Fig. 3 Construction of a modern dual coil geophone

Mechanical Features

A geophone consists of the geophone system (basic unit) and the geophone case. The geophone system comprises all units shown in the sketch of figure 1: spring, mass, magnet, and a cylindrical container (Fig. 2, a)) in which they are housed. The geophone case differs according to whether it is to operate on land, marsh, or underground. The material of the case is normally synthetic but metal is also used. The case must be able to withstand high mechanical forces and temperatures.

Figure 2 shows different types of cases and spikes by which the geophone is planted and thus coupled to the ground. For coupling to very hard ground, differently formed base plates (flat, conical or tripod e. g.) are used.

Figure 2 also shows two ways of connecting the cable to the case. The bottom takeout (geophone b,) has the advantage that the cable can be led close to the ground. However, the geophone can only be put into the ground up to the takeout. The top takeout (geophone b3) avoids this disadvantage. But, even when correctly planted, it is more vulnerable to wind noise.

A possible mechanical construction of a modern geophone system is shown in figure 3. The dual coil together with the coil-form are the moving mass which is held by springs at its top and bottom. The springs are rigidly clamped at the connections of the magnet with both lids. The coil can move in the direction of the geophone' axis as far as the pole pieces of the magnet allow. This is the normal mode of operation.

However, the geophone - as a three dimensional body - has three degrees of freedom, that means it can also move perpendicular to its axis - as far as the air gaps allow - and it is capable of torsional vibrations. When measuring in more than one plane, say in case of longitudinal and shear waves as well, and at higher frequencies, these types of oscillation can be disturbing.

Electrical Features

Noise pickup by external magnetic fields is kept small by use of dual coil geophones. Both halves are electrically connected in series. Voltages induced by external fields are cancelled, signal voltages enforce each other.

When comparing geophones it must be borne in, mind that the electrical output depends - neglecting small scatterings - on their size. The coil space given by the geophone size can be filled with a large number of turns with wire of small diameter or with only a few turns of a large diameter. Sensitivity and coil resistance, respectively, are both either high or low.

Essential Features for the kind of operation and for quality criteria are:

- Sensitivity
- Coil resistance
- Resonant frequency
- Damping
- Distortion
- Spurious resonances

These terms should now be explained:

Sensitivity is the amplitude quotient of the geophone output voltage and the ground velocity. It is measured in volts per inch (or centimeter) per second. The relation between sensitivity and frequency is described by figure 4.

The coil resistance is the resistance measured by an ohmmeter across the geophone terminals.

The geophone when excited by a short impulse oscillates with decaying amplitudes (Fig. 5). The frequency of oscillation is the **Resonant frequency** of the geophone. The rate of decay is a measure for the **Damping**.

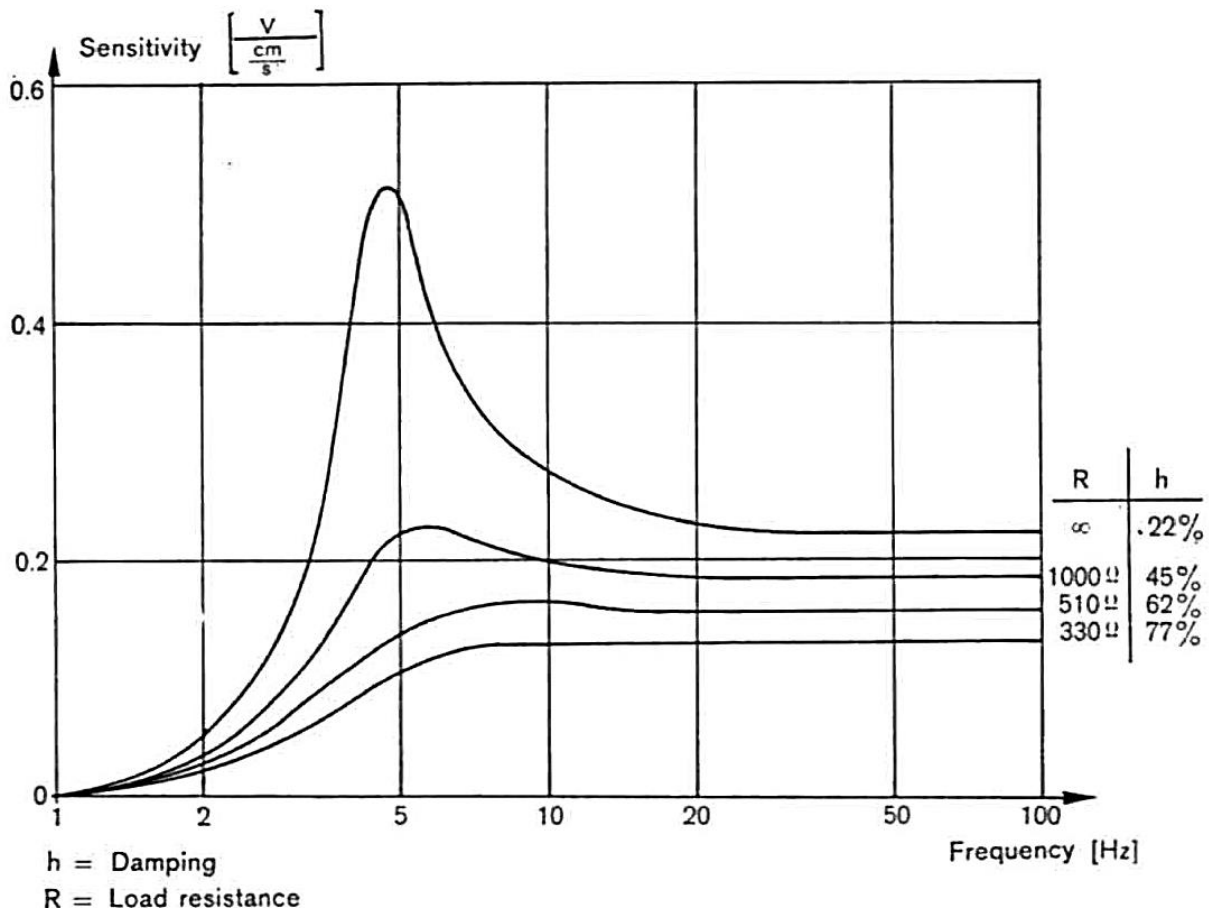


Fig.4 Geophone sensitivity versus frequency

Fig. 5 Measurement of damping

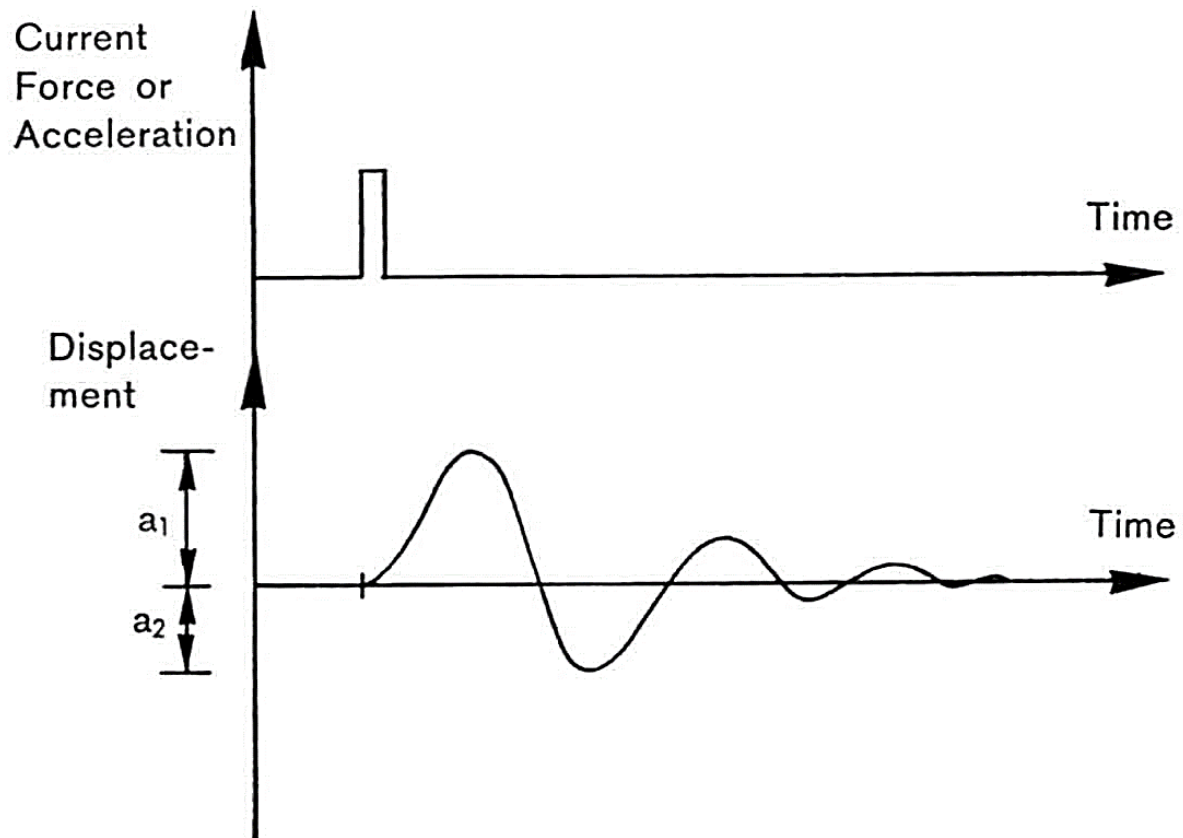
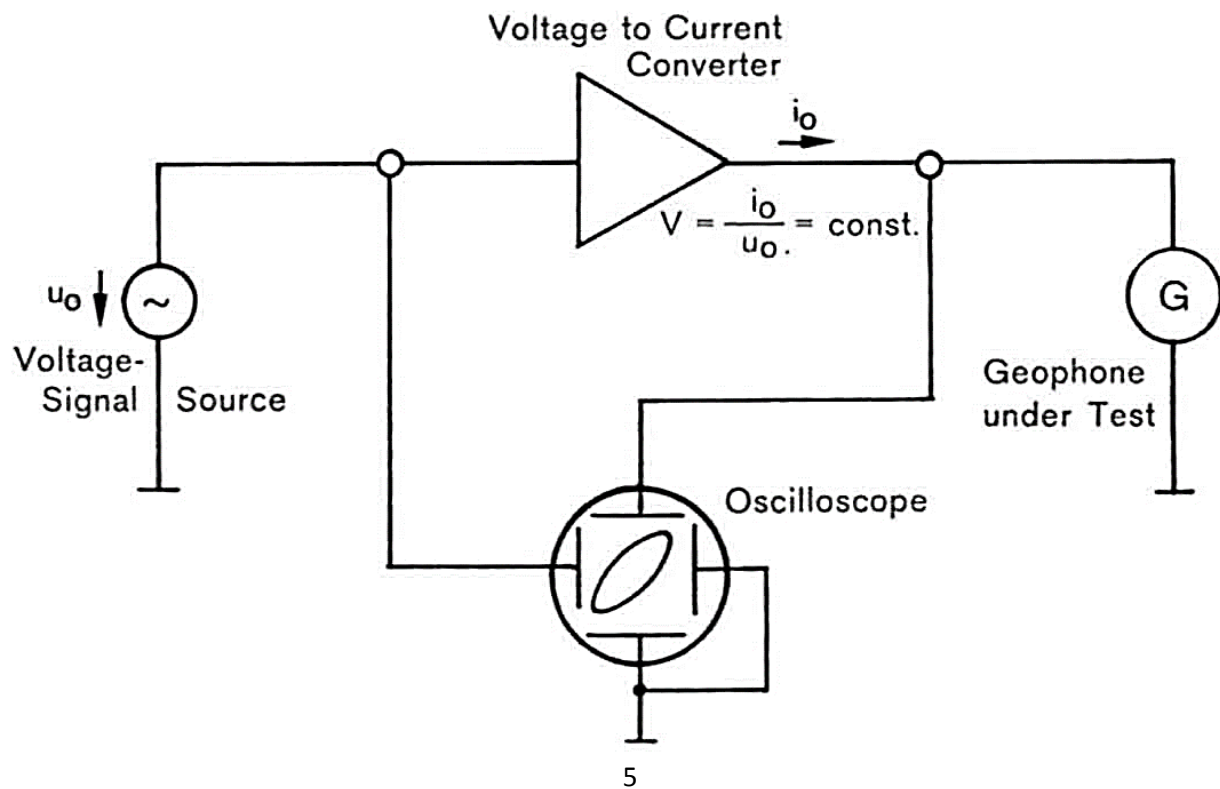


Fig. 6 Measurement of resonant frequency



The resonant frequency (Fig. 6) depends on the spring constant, the size of the moving mass, and the internal and external damping. It must be kept within close tolerances because it determines the filter characteristic of the geophone which in turn influences the reliability of the measured travel times. Therefore, damping is necessary.

The internal damping is partially due to unavoidable mechanical dissipation. Another part is intentionally produced by the manufacturer. This kind of damping is caused by eddy currents in the coil form or by the resistance of a viscous fluid (e.g. oil) by which the moving parts can be surrounded.

The external damping is caused by the current, flowing from the geophone through the cable and the input resistance of the field system. The geophone can be regarded as an electrical generator, differing from others only in the kind of movement by which the electrical energy is produced. This movement is linear (up and down) instead of rotational.

The pole piece is mostly shorter than the half-coil (see fig. 3) and, therefore, the coil moves partially within the in-homogeneous part of the magnetic field. In the case of large amplitudes, the coil moves to a greater extent in this in-homogeneous region. The result of this is that the linear relationship between motion and voltage is less well obeyed than with small amplitudes. The consequence is distortion that means the geophone generates harmonics in addition to the voltage at the exciting frequency.

The geophone construction ' in figure 3 is only one of several possible variations. For instance, the length of a half-coil can also be 'smaller than the pole piece. Of course, this would not change the situation as to distortion, in principle.

It has already been mentioned that in addition to its primary motional mode the geophone is capable of horizontal and torsional oscillations relative to its axis of symmetry, especially if planted in the ground with a tilt. The horizontal compliance and the torsional stiffness of the springs together with the mass and its polar moment of inertia, respectively, determine these unwanted motional modes. The resonances of these modes are called **spurious resonances**. Their frequencies are near to 170 Hz for geophones in use today.

The frequency band of "normal" reflection-seismic records ends at 124 Hz so that spurious resonances don't matter. The spurious resonances of "high-resolution geophones" lie above 170 Hz. The same excitation in vertical as in horizontal direction produces voltages with amplitudes differing by 50 dB.

One of the geophone terminals is distinguished from the other by a special mark, such as a small cross, thus enabling determination of the polarity. Normally, the geophone generates a voltage positive with respect to this marked terminal if excited by a mechanical impulse from below in the direction of the geophone's axis of symmetry. Marking one geophone terminal thus should guarantee the right electric connection within the geophone strings to produce signal voltages reinforcing each other. A historical review on the evolution of geophones with PRAKLA-SEISMOS will be given in the second part of this article published in the Report 4/76.

THE GEOPHONE (2) (Prakla)

Its essential features and the related test procedures, **Second part.**

Geophone testing with PRAKLA-SEISMOS is done routinely by the crews and in the technical department in Hannover. Because of the large number of geophones to be checked (each seismic party has about 3000 geophones in operation) the test method must be a compromise between extent and accuracy of tests, time needed, and simplicity of the test set.

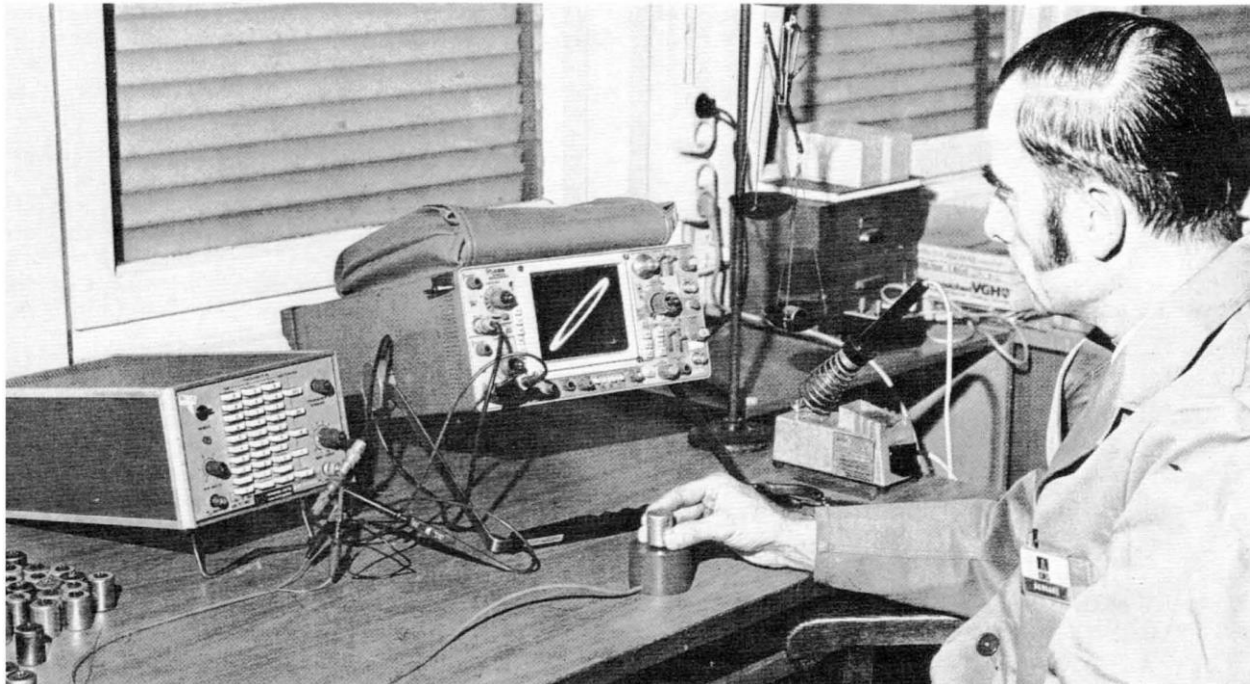
The man at the geophone line only needs a tool that tells him: "O. K." or not "O. K.". He hasn't the time or the opportunity to look for the cause of a geophone failure. The operator or the field office have tools at their disposal like a cable checking device and an oscilloscope to further locate the discrepancies such as coil resistance, resonant frequency and polarity. These are for sure essential features of the geophone. The remaining parameters (e.g. damping and distortion) up to now determined sporadically in the Technical Department in Hannover only, will be measured by the crews as well in the near future.

Test Methods

Geophone specifications can either be measured absolutely or relatively, using mechanical or electrical excitation. The individual parameters such as sensitivity, resonant frequency, coil resistance, distortion, polarity etc., may be either measured individually or several at the same time.

The first thing is to find a standard geophone or a standard string which is representative for a spread. Measuring several parameters at one time (impulse method) is the quickest, most comprehensive and thus the most economical method.

G. Schnake at his test set in the Technical Department



Measuring individual parameters is necessary when checking the geophone specifications given by the manufacturer or to find a standard geophone or a standard string.

Mechanically exciting a geophone would be the approach matching the operational conditions best. However, such an application is scarcely possible because a shaker table would have to be large enough to allow the economical checking of entire strings. In addition, the allowable distortion would have to be in the order of 0.01 % to enable the measurement of geophone distortion of ca 0.2 %. These severe requirements exclude in practice the mechanical excitation.

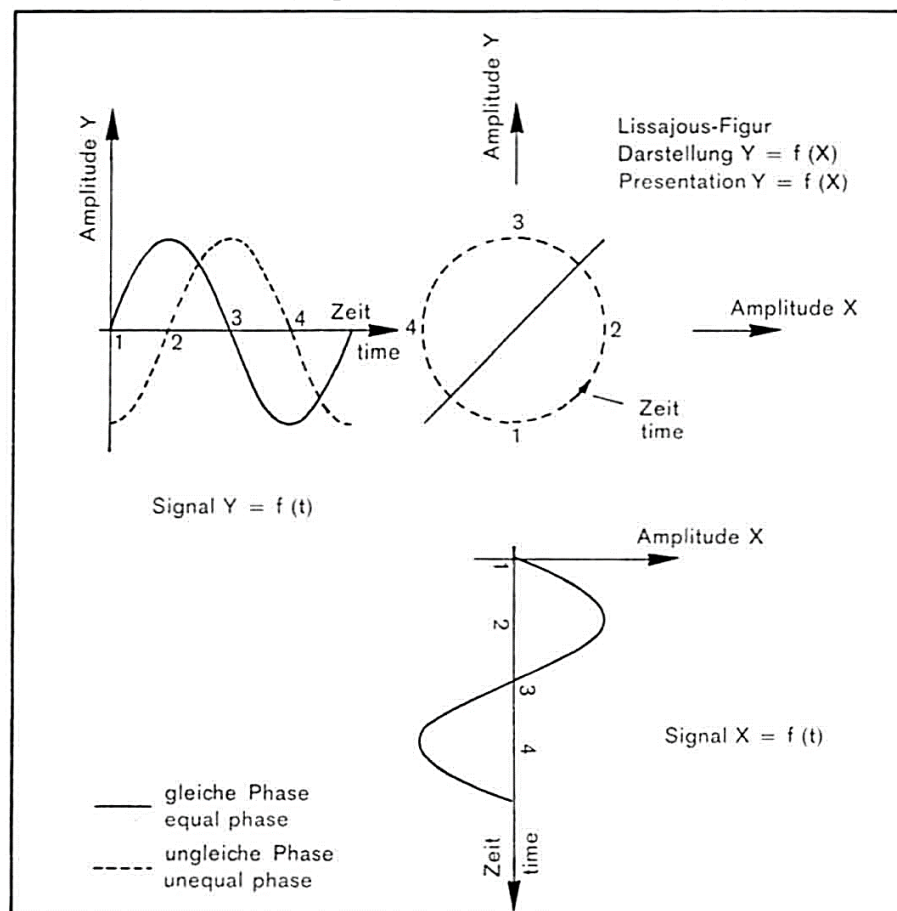
Electrically exciting a geophone is an indirect method because in this case the geophone is treated as a linear motor whereas it works as a generator in normal operation. However, it is in this way possible to measure all parameters, except coil resistance, with the required accuracy. This is true both for a single geophone and for strings either in the crew or in the Technical Department in Hannover.

Measuring individual parameters

Sensitivity

When exciting the geophone mechanically the amplitudes of the velocity and the output voltage must be measured. The ratio of these values is the wanted sensitivity. Although very simple in principle, this method is not applied in practice.

Fig.1 Resonant frequency measurement by Lissajou figures



The basic idea of electrical excitation is as follows:

The geophone as a motor takes up an electrical power in proportion to its mechanical motional energy via its terminals. More specifically, the geophone presents a measurable impedance (motional impedance) across its terminals. As the sensitivity represents a measure of the relationship between electrical and mechanical behavior, the impedance must be related to it as well. Therefore, from measuring the impedance we know the sensitivity by mere calculation.

Coil resistance

The coil resistance is a pure ohmic resistance. It can therefore be measured by an Ohm-meter.

Resonant frequency

Let us assume the geophone to be driven by a voltage the frequency of which deviates from its resonant frequency. The geophone operates in this case as a motor. The power flowing into it consists of two parts. The first part is dissipated in the coil resistance and by mechanical friction and converted to heat, the second part oscillates between the electrical source and the mechanical system consisting of mass and spring. The second part is zero if the geophone is excited by its resonant frequency, i.e. the geophone consumes only true power. This again means that the voltage at its terminals and the current are in phase. The phase equality can best be checked by Lissajou-figures, see figure 1.

Damping

From the description of the damping in the first part of this article in the PRAKLA-SEISMOS report 3/76 a simple measuring method can be derived: The geophone is excited by a short pulse, two successive peak values of the oscillating output voltage are measured, and the damping is calculated from the amplitude quotient a_1/a_2 , see figure 2.

It would be very difficult to generate such a pulse mechanically which is sufficiently stable and accurate. An electrical impulse is for example a current pulse of about 1 ms duration, in general one order of magnitude smaller than the expected time of the period of the oscillation, for example 10 ms.

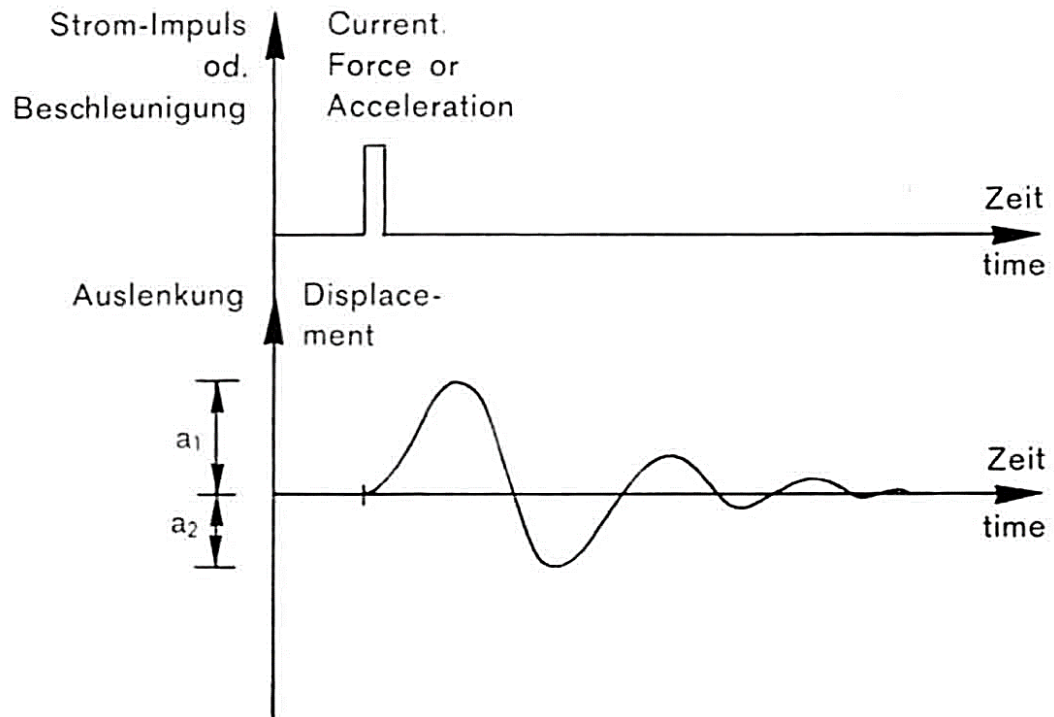
The current pulse appears to the mechanical system as a force- or an acceleration pulse. The coil starts moving which in turn generates an output voltage. This voltage is evaluated.

Distortion

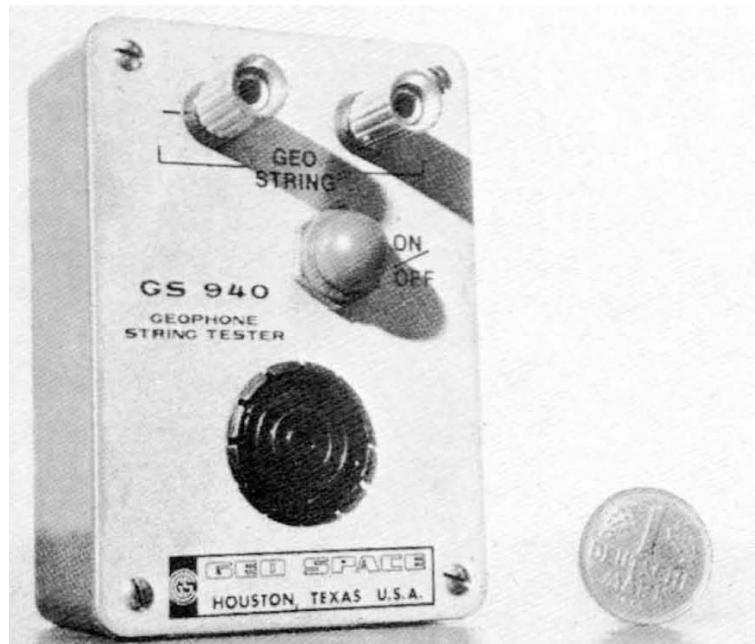
We already know that the mass (i. e. coil and coil form) of the geophone system gets during its motion into increasing inhomogeneous areas of the magnetic field. This means a sinusoidal motion doesn't generate a sinusoidal voltage at the terminals, in other words the voltage contains harmonics, and so does the current driven by this voltage through a pure ohmic resistance.

When measuring distortion the geophone operating as a motor is forced to draw a pure sinusoidal current. This is based on the idea already described in connection with the measurement of the sensitivity: the resistance between the geophone terminals is - apart from the coil resistance - the motional resistance (resonant frequency = measuring frequency). Ohm's law requires that a pure sinusoidal current develops a pure sinusoidal voltage across this resistance. Harmonics of this voltage must be due to the motion in the geophone.

.Fig. 2 Measurement of damping



Geophone -Tester



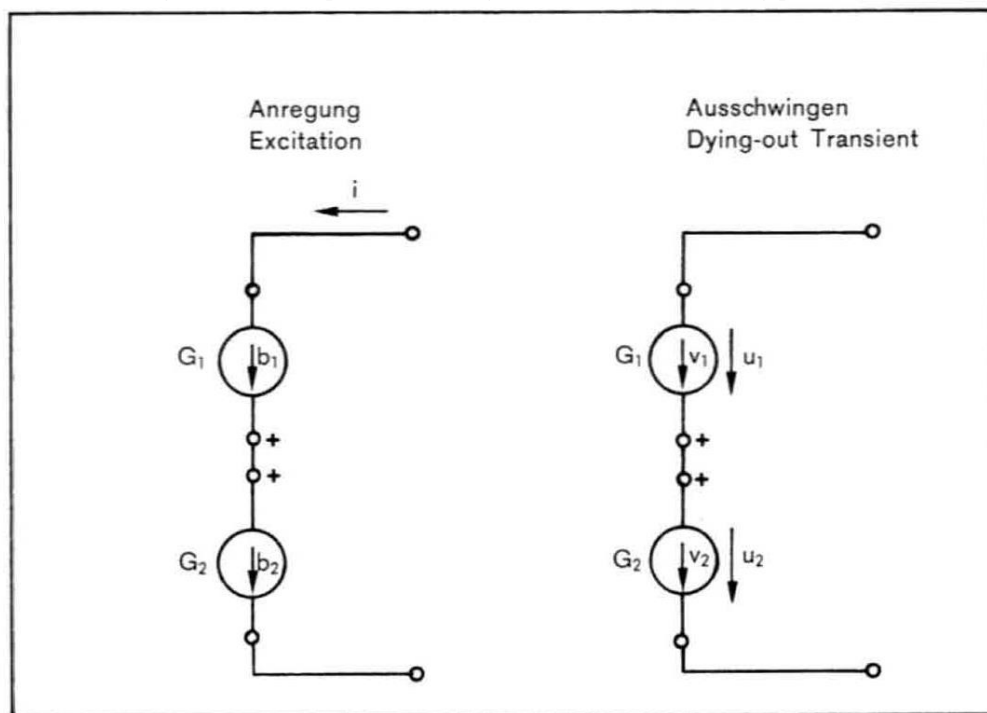
Measuring the resultant effect of several parameters

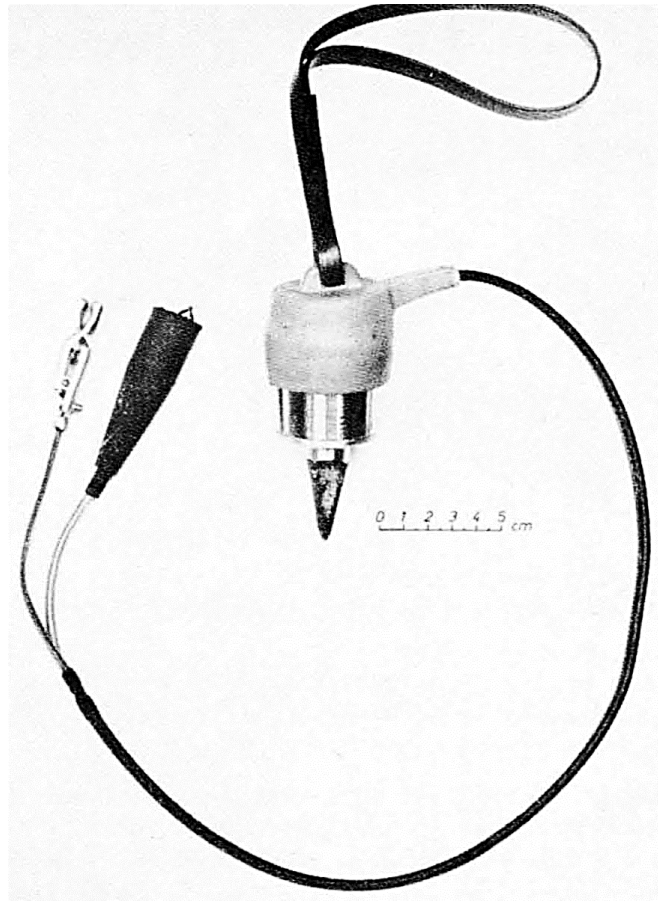
The method using short pulse excitation enables the simultaneous measurement of several geophone parameters. However, as far as it has been used up to now in tools operating on the spot the only statement is: The geophone is working properly or it isn't. In case it doesn't work, the individual parameters must be checked because every single one of them may be the cause of the failure.

A drawback of the method however is its principal inability to indicate one of the most frequently encountered errors: wrong polarity. To explain this, we assume two geophones

G1 and G2 to be connected in series with reversed sequence of their terminals. They are excited by the same current pulse. The mass of G1 is moved upward, the mass of G2 consequently downward. They deliver voltages of opposite polarity with respect to an identical terminal of each single geophone. Because of the reversed order of the contacts, however, these voltages are lined up with equal polarity (figure 3) in the series connection. They cannot be discriminated from each other on the basis of polarity.

Fig.3 Electrical pulse method fails in determination of polarity





G 25 Reflection geophone

Retrospect on the development and application of geophones at PRAKLA, SEISMOS and PRAKLA-SEISMOS

Data given below are possibly not quite complete. A continuous documentation on the application of seismographs or geophones has unfortunately not been made. The following data are partially based on oral tradition by older members of our companies. In this context we have to mention Dr. H. W. Maass and Dr. W. Beuermann in the first place. Moreover, Dr. H. W. Maass is essentially the responsible writer of this part of the article.

REFLECTION GEOPHONES

In the Federal Republic of Germany the modern era in seismics began in 1948 from a technical point of view when PRAKLA and SEISMOS received one NGC-reflection seismic measuring system each and a set of NGC-geophones.

Before, both companies used seismographs of their own development and construction. SEISMOS had already started to build seismographs - then called pendulum - in 1930. In 1934 an improved version had an electromagnetic system whose swinging lever was suspended between the poles of a permanent magnet by means of leaf springs. Its specifications:

Resonant frequency ca 35 Hz, sensitivity ca 0.85 V/cm/s. coil resistance 400 Q , weight 3 kp, number of built seismographs ca 1000. The leaf-spring-lever-construction combined with the electromagnetic transducer was used by SEISMOS for another 20 years. PRAKLA developed, built, and used already in 1936 (F. Trappe and W. Zettel, DRP 707 257) the electromagnetic moving coil transducer.

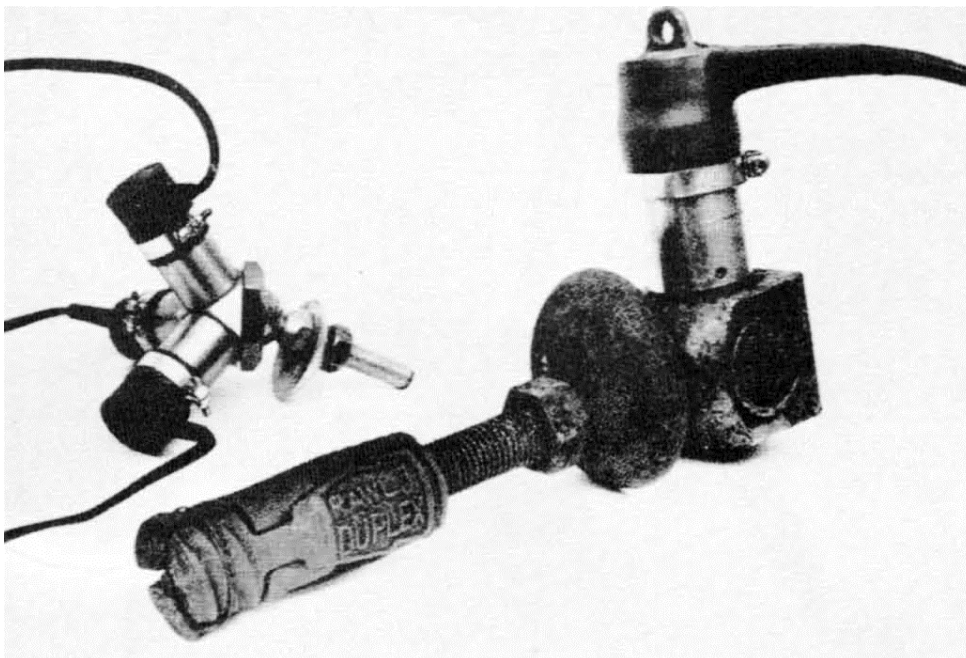
The NGC-geophone, type 14-A, was very similar in construction to a moving coil loud speaker it had already all the characteristics of a modern geophone: Rotational symmetry of the electrodynamic transducer, of the springs and of the guidance (centering).

SEISMOS manufactured a corresponding reproduction type in its own workshop, PRAKLA had its reproduction type G-11 produced by "Labor Wennebostel". These geophones had a resonant frequency above 30 Hz and a weight of about 1.5 kp. In accordance with the need at that time only some hundreds were built.

Improvements in material for magnets (Alnico) and springs (Beryllium-Copper) allowed the construction of geophones of smaller size. About 1951 a geophone from Southwestern

Industrial Electronics (SIE), Houston, came onto the market with a resonant frequency about 25 Hz, and which weighed 0.6 kp only. PRAKLA ordered a corresponding reproduction type from Labor Wennebostel in the same year. Only scarcely 100 geophones of this type (G-15) were built.

Three component geophone with spread anchor fastening



In 1952 SEISMOS introduced equivalent Century-Geophones (Century Geophysical Corp., Tulsa). The further development (ca 2000 of them) led to a greatly reduced size with the following data: Resonant frequency 18 Hz, sensitivity 0.44 V/cm/sec, weight ca 0.2 kp.

In 1952 PRAKLA developed the type G-21 with a resonant frequency of 24 Hz and a weight of 0.5 kp, over 2000 geophones of this type were manufactured by the company Nass/Hannover. In 1953 the geophone G-25 was introduced which was a further development of G-21 with higher sensitivity. Nass/Hannover manufactured over 20,000 of this type for PRAKLA up to the year 1962.

Starting in 1955, SEISMOS put Hall-Sears geophones (Hall-Sears Inc., Houston) into operation. It was first an intermediate site which was replaced by the type HS-J in 1961. By this type the peak of miniaturization was achieved. The geophone HS-J had a resonant frequency of 14 to 28 Hz, its weight was below 0.1 kp. PRAKLA applied this geophone in great numbers as well. In 1973 there were still 18,000 of them in operation with PRAKLA-SEISMOS.

Digital technique stopped the desire for miniaturization. Recording quality took first priority and led to the acquisition of geophones from Sensor with again a higher weight of about 0.2 kp. In 1973 there were 40,000 SM geophones in operation with PRAKLA-SEISMOS: 5,600 SM 1, 22,150 SM 2, and 13,150 SM 4. In addition, there were 2800 marsh geophones - either equipped with HS-J or with SM 4 - units, and 615 shallow water geophones - type HGL equipped with Sensor-units – ready for use.

The fully developed geophone of today as applied in seismics has essentially the following characteristics: Two biased springs to maintain a faultless movement of the coil, (springs biased for compensation of the weight of the mass), measures to avoid torsional and horizontal oscillation modes and tune resonances, dual coil construction to reduce electrical noise pickup, filling with a dry inert gas, and a hermetically sealed case.

To terminate the chapter on reflection geophones it shall be mentioned as a curiosity that a handy geophone from B. Marsch appeared on the German market around 1948 based on the transducer principle of a carbon microphone (changing pressure produces a resistance variation). However, it disappeared quickly after a short experimental operation.

REFRACTION GEOPHONES

At first, the same seismographs were used in reflection and refraction seismics. Later, refraction geophones were developed with specially low resonant frequencies.

The leaf-spring-lever construction survived for very low frequency application. From 1954 on, SEISMOS built about 250 refraction geophones of the type 3S-3 with a resonant frequency of 2.8 Hz, a sensitivity of 2.5 V/ s/cm, a coil resistance of 400 Q, and 6 kp of weight. This geophone was partially equipped with a transistor-preamplifier in 1957.

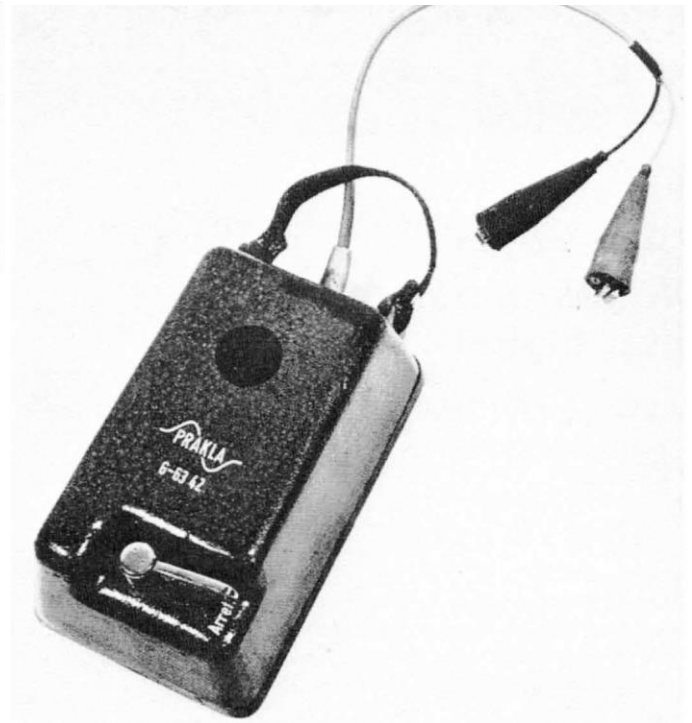
In 1960 the 3S-3 geophone was further developed to the type 3S-1 which had an adjustable resonant frequency between 0.8 and 1.1 Hz and a bimetal strip for temperature compensation (DBP 1 151 948).

At first PRAKLA tried to improve the lever geophone by mechanical amplification via a double lever (DBP 1184 096, A. Stein, 1960).

.Refraction geophone G 63



The idea of magnetic suspension led to the development of the rotationally symmetry refraction geophone G-61. Moreover, the refraction geophone G-63 with torsion bar suspension was designed (DBP 1 177352, Barteis, 1962). But none of these geophone types proved true under rough field conditions and therefore they were withdrawn from operation after short experimental application.



PRAKLA then introduced the modern refraction geophones from Hall Sears: Type HS 1 with 4.5 Hz resonant frequency, 0.269 kp to 0.68 kp weight depending on the construction (aluminium or brass) or the operational conditions (land or marsh), further the type HS 10 with 1 Hz resonant frequency and 4.8 kp weight, and later the Sensor geophone type SM 1 with 7.5 Hz resonant frequency and a weight of 0.254 kp.

In 1973 PRAKLA-SEISMOS was in possession of 1710 refraction geophones of which 990 were of the type HS 1 220 of type HS 10 and 500 of type SM 1.

